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High-Strength Fiber-Reinforced Concrete Containing Technogenic Raw Materials and Composite Binders with Use of Nanodispersed Powder

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Abstract: The study examines the aspects of use of technogenic raw materials and a composite binder with use of nanodispersed powder derived from hydrothermal springs in production of high-strength fine-grained fiber-reinforced concrete. There were carried out experimental investigations of fiber-reinforced concrete samples containing cement and a composite binder. Inclusion of steel wave-type fiber in an optimal dose into the concrete mixture, high-density filler packing, use of composite binders and nanodispersed powder allow obtaining fine-grained concrete based on technogenic raw materials with the ultimate compression strength of 160.0 MPa and the ultimate bending strength of 31.2 MPa. There were offered the principles of optimization of the structure of fine-grained concretes at nanolevel due to use of a compound binder and nanodispersed powder at microlevel due to ensuring high-density filler packing; at macrolevel due to inclusion of steel fiber.

Key words: Fine-grained concrete, technogenic sand, fiber-reinforced concrete, microlevel, steel fiber

INTRODUCTION

The scientists from Austria, Australia, Belgium, Germany, the Netherlands, Spain, Canada, China, Poland, the USA, France, the Czech Republic, Switzerland, the Republic of South Africa, Japan and other countries contributed to development of steel-fiber-reinforced concrete science (Brandt, 2009; Fernandes, 1976; Herr, 2001; Beaudoin, 1990; Maidl, 1995; Piasta *et al*., 1985).

During the last years in Russia there are observed considerably increased rates of construction and commissioning of facilities for various applications. At the same time many regions of Russia experience lack of raw-materials base of high-quality concrete fillers meanwhile there are widely occurring deposits of technogenic sands. Use of the mentioned materials requires special approach at time of designing concrete compositions and technologies of their production in this connection technogenic sands are not sufficiently used. In order to decrease production cost of fiber-reinforced concrete mixture it is offered to use technogenic raw materials, namely Quartzitic Sandstone Fines (QSF) as a filler of fine-grained fiber-reinforced concrete.

Application of fiber reinforcement will result in advancement of strength and rigid characteristics of products and structures which will allow increase of useful life of buildings and structures constructed with use of such materials by many years (Klyuyev *et al*., 2012).

MAIN PART

Influence of a filler shape and texture on concrete strength is not known but potentially more rough structure will give higher adhesive power between particles and cement matrix. Besides, larger surface area of angular-shaped filler means a capability to produce higher adhesive power (Klyuyev, 2011a; Klyuyev and Lesovik, 2011). The carried out investigations by means of Raster Electron Microscopy (REM) demonstrated that fines produced by crushing and quartzitic sandstone fines have rough surface and angular shape in distinction from natural sands with smooth surface and round shape of grains (Fig. 1).

Principal physical and mechanical properties of fillers are shown in Table 1. Binder TMC-100 was obtained by means of regrinding of Portland cement CEM I 42.5 N per GOST 31108-2003 for getting the specific surface of Sspec≈500 m^2 kg^{-1}. Binder VNV-100 was obtained by mixed grinding of Portland cement and plasticizing agent SP-1 in an optimum dose (0.6% of the binder weight) for getting the specific surface of Sspec≈500 m^2 kg^{-1}.

The structure of hardened cement paste containing CEM I 42.5 N and VNV-100 is shown in Fig. 2. The structure of hardened cement paste containing a composite binder is moredense as compared to standard Portland cement, it is represented by very dense packing of grains in the total weight of newgrowths.

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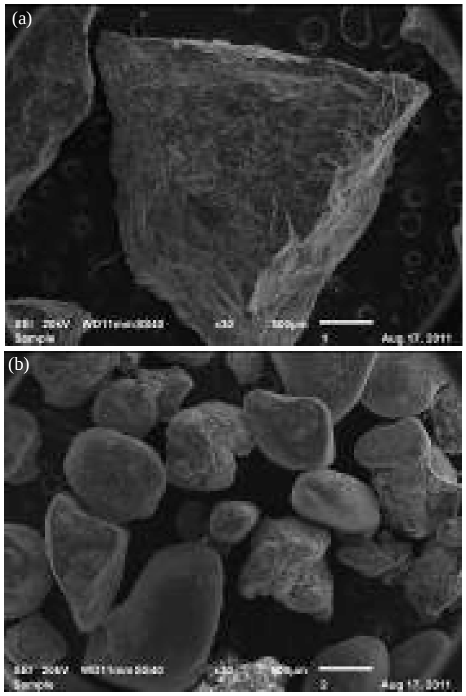

Fig. 1: A grain of: a) quartzitic sandstone fines and b) natural sand

Physical and mechanical properties of composite binders are given in Table 2. In order to modify concretes for obtaining high-strength mixtures there were developed the compositions of fine-grained fiber-reinforced concrete based on technogenic raw materials and a compound binder with use of Nanodispersed Powder (NDP) obtained from hydrothermal waters by the method of separation.

Powder introduced into the cement samples as a nano-additive had the specific surface area equal to 156000 m^2/kg (the values were determined by means of low-temperature adsorption with use of a porometer ASAP-2010 N Micromeritics), the average diameter of particles made 7.3 nm, density made 35 kg/m^3 (Fig. 3).

Nanodispersed powder in the amount of 0.2% of the cement weight was mixed with the water phase before the mixture tempering. Ultrasound treatment ensured homogenous distribution of powder particles in the volume of liquid.

Table 1: Physical and mechanical properties of fillers

Index	Crushing fines QSF	Tavolzhan sand
Fineness Modulus	3.50	1.38
Bulk density (kg/m^3)	1490.00	1448.00
True density (kg/m^3)	2710.00	2630.00
Void coefficient (%)	47.80	44.90
Water demand (%)	5.50	7.00

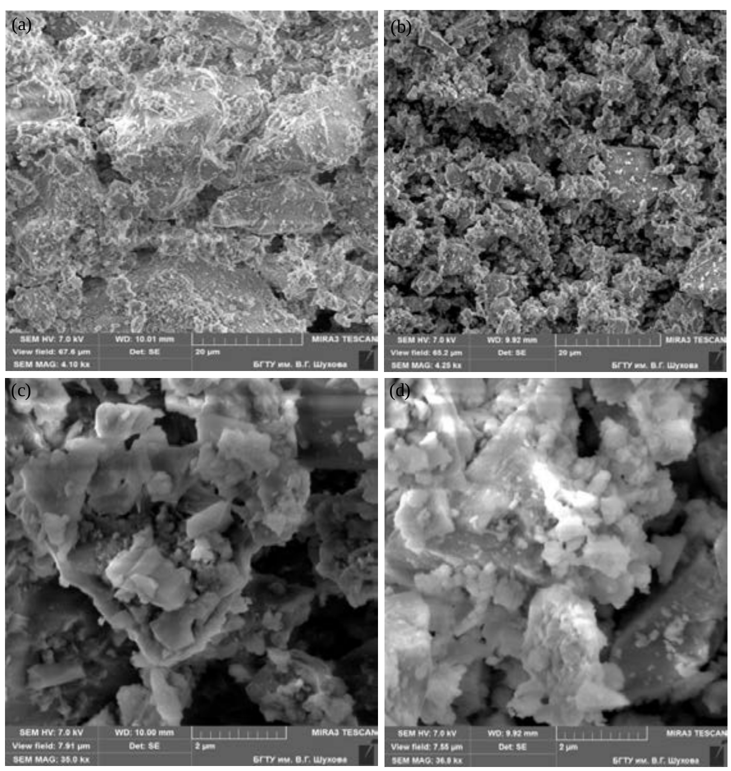

Fig. 2: Microstructure depending on the properties of a binder: a, c) morphology of newgrowths of hardened cement paste CEM I 42.5 N and b, d) morphology of newgrowths of hardened cement paste VNV-100

Inclusion of NDP into the cement system allows increase of activity of a binder up to 30% which is explained by improvement of the structure of hardened cement paste. The earlier investigations demonstrated that hardened cement paste with the optimum dose of NDP is characterized by more dense matrix consisting of low-basic hydrous calcium silicates while hardened cement paste without the additive is represented by more high-basic hydrous calcium silicates and hexagonal plates of Portlandite.

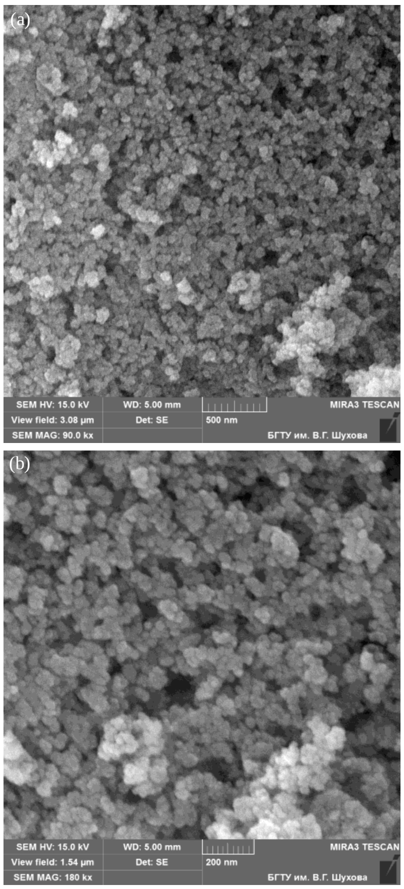

Fig. 3: General view of nanodispersed powder

Nanodisperse constituents promoting earlier binding of Portlandite intensify the process of cement minerals hydration. At the same time larger parts of NDP function as crystallization nuclei and a micro-filler by reducing shrinking deformation and improve performance characteristics of the composite. Characteristic feature of the structure of hardened cement paste with NDP is substantially smaller number of microfractures. Inclusion of nanoparticles of silicon dioxide resulted not only in ultimate compression strength increase but also in strength development acceleration in the samples with nano-additives.

The carried out experimental investigations (Klyuyev, 2011b, c; Klyuyev and Lesovik, 2012; Lesovik and Klyuyev, 2011; Klyuyev *et al*., 2010, 2013, 2011) showed that steel wave-type fiber with the length of 30 mm and the diameter of 0.8 mm with the optimal reinforcement of 3% of weight is the most efficient reinforcement additive.

In order to evaluate possibility to use technogenic raw materials, namely quartzitic sandstone fines for production of high-strength fine-grained fiber-reinforced concrete there were developed compositions on its basis. For achievement of High-Density Packing (HDP) of the filler sand from Tavolzhanskoe deposit was used. Portland cement CEM I 42.5N and composite binders containing NPD were used as binding agents (Table 3-5).

The investigation of physical and mechanical properties showed that fiber-reinforced concretes containing VNV-100 in all of the cases exceed the properties of the samples with analogous composition but with use of other binders. Therefore it can be concluded that use of composite binders with addition of a superplasticizer ensures significant improvement of strength properties of concrete.

Table 2: Physical and mechanical properties of compound binders

Binder types	Normal consistency of cement grout (%)	Setting time (h, min)		W/C ratio	Binder activity (MPa)	
		Start	End		Binding	Compressing
CEM I 42.5 N	26.2	2-40	4-50	0.40	7.2	48.9
TMC-100	25.3	2-20	4-10	0.44	10.2	71.3
VNV-100	22.8	2-10	3-30	0.28	12.4	85.2

Table 3: Physical and mechanical properties of fine-grained concrete depending on a binder type

Binder types	Material consumption per Ha 1 m^3 of mixture				NDP (kg/m^3)	Steel fiber (kg/m^3)	Ultimate compression strength (Mpa)	Ultimate bending strength (MPa)
	Binder (kgm^3)	Crushing fines QSF (kg/m^3)	Sand (kg/m^3)	Water (l/m^3)				
CEM I 42.5 N	810	1100	340	204	-	-	56.3	14.3
CEM I 42.5 N+HDP	810	1100	340	208	-	-	67.7	15.1
CEM I 42.5 N	810	1070	340	195	-	75	86.8	17.4
CEM I 42.5 N+HDP	810	1070	310	197	-	75	97.7	18.2
CEM I 42.5 N+HDP	810	1070	310	197	0.2	75	119.4	22.7

Table 4: Physical and mechanical properties of fine-grained concrete depending on a binder type

	Material consumption per Ha 1 m^3 of mixture							
Binder types	Binder (kg/m^3)	Crushing fines QSF (kg/m^3)	Sand (kg/m^3)	Water (l/m^3)	NDP (kg/m^3)	Steel fiber (kg/m^3)	Ultimate compression strength (MPa)	Ultimate bending strength (MPa)
TMC-100	810	1100	340	209	-	-	65.7	15.5
TMC-100+HDP	810	1100	340	213	-	-	77.3	16.7
ÒÌÖ-100	810	1070	310	199	-	75	92.6	19.1
TMC -100+HDP	810	1070	310	201	-	75	102.4	20.5
TMC -100+HDP	810	1070	310	201	0.2	75	127.1	26.5

Table 5: Physical and mechanical properties of fine-grained concrete depending on a binder type

	Material consumption per Ha 1 m^3 of mixture							
Binder types	Binder (kg/m^3)	Crushing fines QSF (kg/m^3)	Sand (kg/m^3)	Water (l/m^3)	NDP (kg/m^3)	Steel fiber (kg/m^3)	Ultimate compression strength (MPa)	Ultimate bending strength (MPa)
VNV-100	810	1100	340	180	-	-	97.5	17.7
VNV-100+HDP	810	1100	340	185	-	-	100.6	18.6
VNV-100	810	1070	310	172	-	75	118.1	22.2
VNV-100+HDP	810	1070	310	174	-	75	125.8	24.1
VNV-100+HDP	810	1070	310	174	0.2	75	160.2	31.2

CONCLUSION

Inclusion of steel wave-type fiber into concrete mixture in an optimum dose as well as high-density filler packing use of composite binders and nanodispersed powder allows achievement of fine-grained fiber-reinforced concrete based on technogenic raw materials with the ultimate compression force of 160.0 MPa and the ultimate bending force of 31.2 MPa.

There were offered the principles of optimization of the structure of fine-grained concretes at nanolevel due to use of a compound binder and nanodispersed powder; at microlevel due to ensuring high-density filler packing at macrolevel due to inclusion of steel fiber.

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